NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

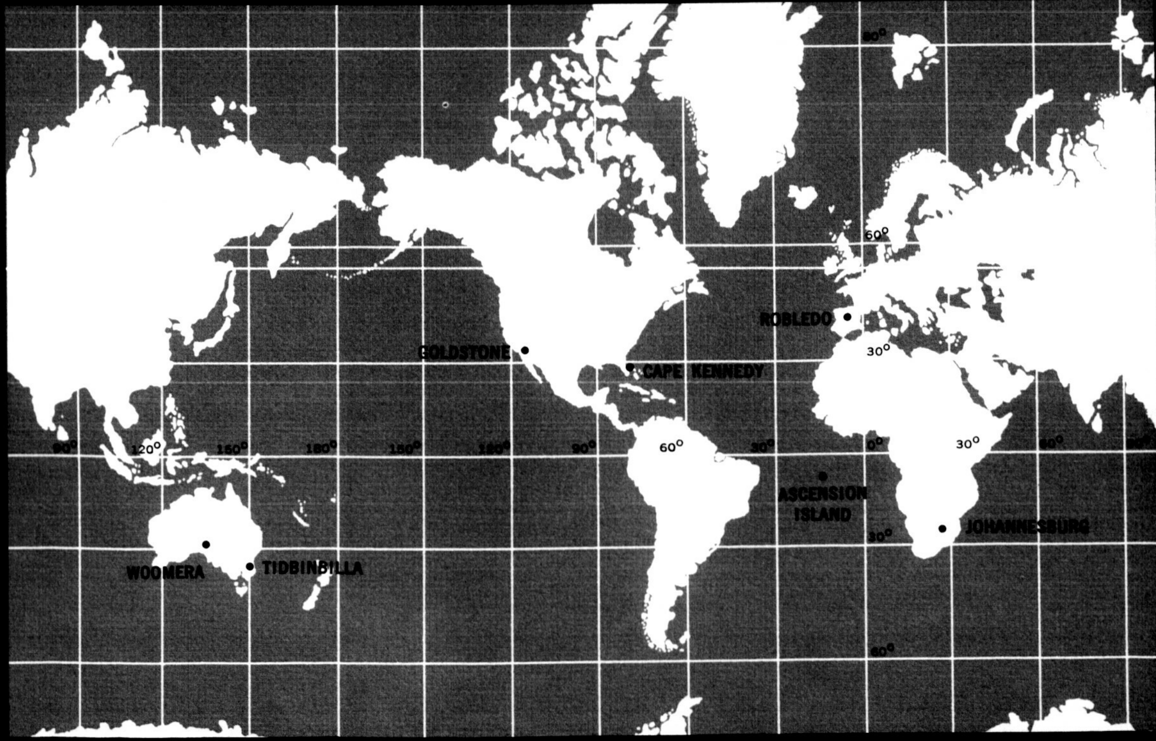
JPL TECHNICAL MEMORANDUM NO. 33-258

DSIF: ROBLEDO

JET PROPULSION LABORATORY/CALIFORNIA INSTITUTE OF TECHNOLOGY

Prepared Under Contract No. NAS 7-100
National Aeronautics & Space Administration

DSIF stations circle the globe at intervals of 120 degrees in longitude to maintain continuous coverage of the spacecraft.



Foreword

A vital element in every National Aeronautics and Space Administration (NASA) space flight project is the communications system which returns data from the spacecraft to its home base and transmits instructions from Earth to the spacecraft. The Jet Propulsion Laboratory (JPL) pioneered the development of many of the critical elements of communications systems designed to function over the vast distance involved in cislunar and interplanetary missions. In 1958 the Laboratory first established a three-station network of receiving stations to gather the data from the first U.S. Earth-orbiter *Explorer I*. Since that time, the network has developed into the Deep Space Network (DSN) specifically designed to communicate with space probes traveling to the Moon and beyond.

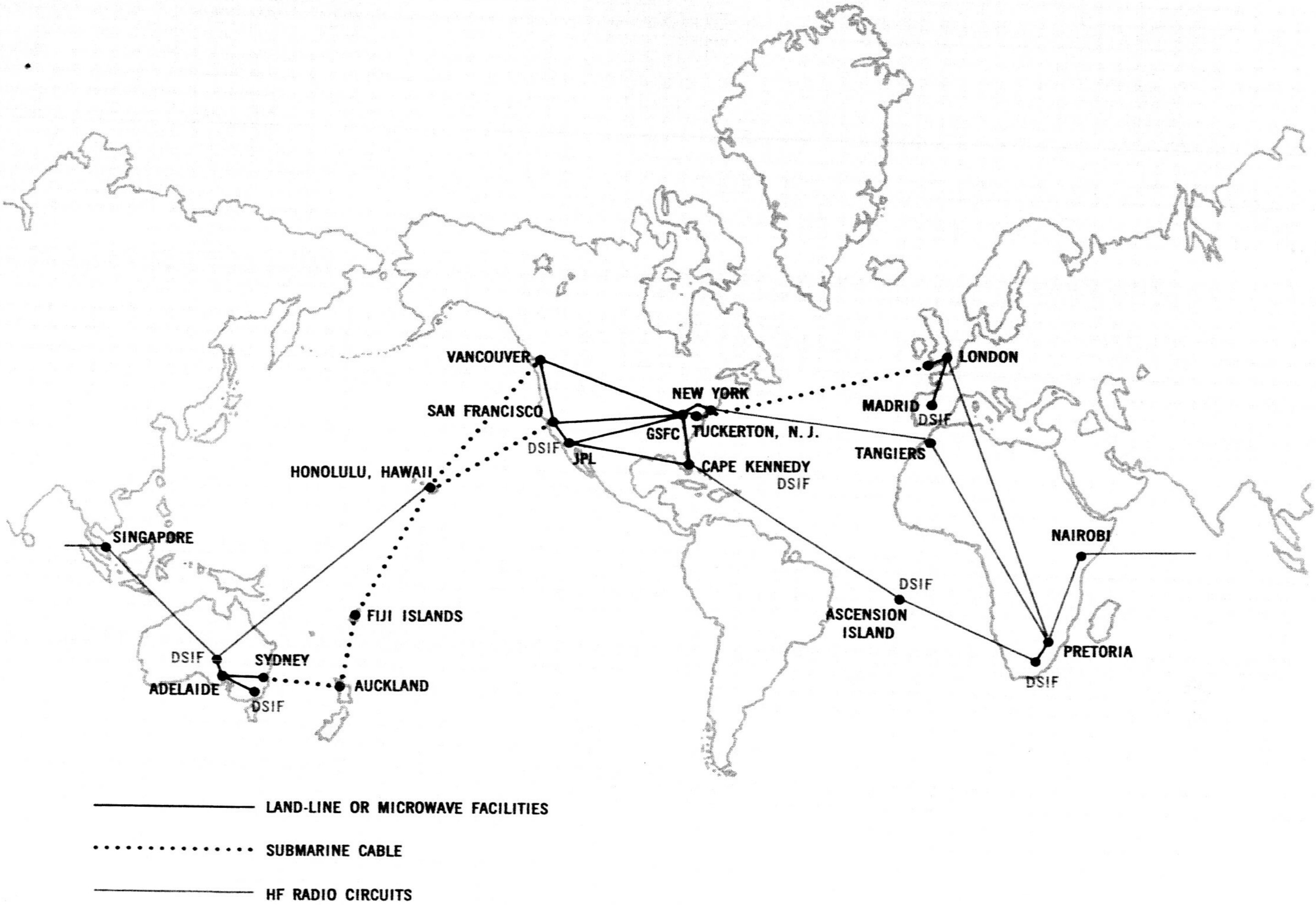
The DSN has contributed to a number of historic U.S. deep space achievements. Among these were the *Mariner II* mission to Venus, the first successful flyby of another planet; the first close-up photographic exploration of the Moon; and the first successful mission to the planet Mars. The capabilities of the Network are continuously being improved in order to keep up with the demands of the more complex deep space missions undertaken by NASA. One of the notable achievements accruing from advanced work of this nature has been radar observations of several planets.

With the establishment of the tracking station at Robledo de Chavela near Madrid, Spain, the DSN has achieved increased capability to support the ever-expanding exploration of space. We gratefully acknowledge the participation of the Instituto Nacional de Técnica Aeroespacial (INTA) in this joint scientific project.

This Technical Memorandum is one of a series which describes the facilities and functions of the various major elements of the Deep Space Network.

W. H. Pickering

W. H. PICKERING
Director, Jet Propulsion Laboratory



GEOGRAPHIC ROUTINGS OF LAND LINES, SUBMARINE CABLES, MICROWAVE AND HIGH-FREQUENCY RADIO CIRCUITS IN A TYPICAL NETWORK OF THE DSN GROUND COMMUNICATION SYSTEM.

Interstation Communications

Robledo has communication with other DSIF stations and the Space Flight Operations Facility (SFOF) at JPL by telephone and teletype through the DSN Ground Communication System, and is linked directly to the SFOF by high-speed teletype for digital data transmission via transatlantic telephone cable.

Teletype is the primary means used for transmitting tracking and telemetry data from the DSIF stations to the SFOF, and for sending predictions and other data to the stations. Analog and TV data channels may be available for some missions. Voice circuits are used for transmission of high-priority communications other than data. Technical control of all communications facilities throughout the DSN is exercised by the Communications Coordinator in the SFOF.

Communications to and from the DSIF station at Robledo normally pass through London. The station has three full-duplex teletype circuits, one high-speed data circuit, and two voice circuits.

Teletype transmission is at the rate of 60 words per minute. On the high-speed data lines, Robledo can "talk" to computers at the JPL SFOF at the rate of 600, 1200, and 4400 bits per second (the 4400-bit rate is about equal to 8800 words per minute). On-site communications at Robledo are handled by telephone, local paging system, and closed-circuit television.

FACING: *Large antennas designed to pick up the faintest of radio signals enable man to listen to messages relayed from space.*

Reaching Into Deep Space

While the idea of transmitting and receiving intelligence over interplanetary distances suggests the need for new and exotic systems, the only practical means known today of communicating with spacecraft is the same basic technology that brings radio and television into our homes —radiation of electromagnetic waves through space. The difference lies in the magnitude of the problem of how to overcome the great losses of energy that occur because of the tremendous distances the signal must travel.

In the brief span of DSIF history, spectacular progress has been made in the evolution of antenna, receiver, and transmitter capabilities, which is fast approaching the technical and theoretical limits for communication within our solar system. Present technology is capable of meeting requirements for tracking, command, and data acquisition at distances ranging up to hundreds of millions of miles from Earth. Sophisticated communications techniques have developed so rapidly that the DSIF capability, measured in quantity of information transmitted per unit of time, has increased more than a thousand times over that of the pre-1960 capability.

To overcome space losses, the DSIF uses antennas designed for high gain, or very high concentration of received signal power, extremely low-noise radio amplifiers, and powerful transmitters that send out a very strong signal. Standard DSIF ground transmitters operate at power levels of 10 kilowatts (10,000 watts). A spacecraft transmitter, on the other hand, is very limited in power because of size and weight restrictions. Very early spacecraft (*Pioneer III*) used power outputs as small as 0.2 watt; the *Ranger IX* spacecraft used two 60-watt transmitters to send back to Earth the images recorded by the six television cameras. Continuing development will increase transmitter outputs for probes contemplated for exploratory missions to the edge of the solar system.

The well-known doppler principle has long been used in determining the relative speed with which a celestial body or star and the Earth are approaching or receding from each other (the radial velocity). The doppler shift is the apparent change in frequency of a signal reflected from or emitted by a moving object as the object moves toward or away from the observer—much as a train whistle is high in pitch as the train approaches, then lower in pitch as it passes.

The doppler principle has been adapted for use in determining spacecraft velocity. Early spacecraft used one-way doppler—measuring the difference between the frequency of a signal transmitted from the spacecraft and the frequency as it is received on the ground, which is proportional to the radial velocity between the Earth and the spacecraft.

The accuracy of the measurement of spacecraft velocity using one-way doppler is limited to about 90 feet per second, because of inexact knowledge of the transmitted

FACING: *Two views of the DSIF antenna with an 85-foot-diameter reflector display the intricate balance of its structural steel ribs and girders. Antenna and supporting structure are as tall as a 10-story building, and weigh about 600,000 pounds.*

The Antenna

The basic DSIF antenna uses a paraboloidal reflector, 85 feet in diameter. The reflector is a perforated metal mirror that looks like an inverted umbrella and is often called the "dish." The antenna and its supporting structure stand 10 stories high and together weigh around 600,000 pounds.

About 8,000 pounds of electronic and operating equipment are an integral part of the antenna structure. This equipment is mounted on the antenna itself and in rooms reached by ladder on the supporting structure. The base for the antenna is a reinforced concrete pad sunk deep into the ground. Whenever equipment is added or moved, counterweights must also be adjusted to keep the structure balanced.

Driving the Antenna

The DSIF antenna is steerable; that is, its "beam" or major radiation pattern can be readily shifted in any direction to follow the spacecraft. When a spacecraft gets out and away from the Earth, it travels in an orbit or path similar to other celestial bodies, and "rises" and "sets" on the horizon like the Sun. The predicted or actual course of a spacecraft is determined by the same methods astronomers use in locating heavenly bodies. That is, the angular position of the spacecraft relative to the star background is defined by a set of imaginary circles (coordinates) corresponding somewhat to Earth longitude and latitude. Each antenna in the DSIF is oriented to a set of local coordinates that are used to measure the antenna-pointing angles by which the spacecraft is located. The DSIF tracking antennas use a system of polar coordinates which measure the hour angle (representing angular direction referenced to a station's local meridian circle) and the declination angle (representing angular direction referenced to the celestial equatorial circle).

The gear system that moves the antenna is polar-mounted. The axis of the polar, or hour-angle gear wheel, is parallel to the polar axis of the Earth. This gear sweeps the antenna in an hour-angle path from one horizon to the other. The declination gear wheel, the smaller of the two gears, is mounted on an axis parallel to the Earth's equator (perpendicular to the polar axis), which enables the antenna dish to pivot up and down. These wheels can be moved either separately or together. The arrangement of the gears allows the beam of the giant reflector to be pointed in almost any direction in the sky.

Movement of the antenna is controlled by the servo system, which consists of electronically controlled hydraulic pumps and motors, gear reducers, and pinions that engage the antenna gear system. Separate servo systems drive the polar wheel and the declination wheel. Electric-motor-driven pumps in the hydromechanical building send high-pressure hydraulic fluid through stainless steel pipes up to the driving motors (mounted on the antenna)

FACING, TOP: *The polar-mount antenna is so-named because the axis of the main gear wheel, or polar wheel, is mounted parallel to the Earth's polar axis. Axis of the declination wheel is parallel to the Earth's equator.*

FACING, BOTTOM: *Close-up view of the polar-mount gear system of the 85-foot antenna shows the large polar wheel and smaller declination wheel, which are rotated to steer the antenna in the direction of the spacecraft as it moves across the sky.*

that actuate the gears. The electronic control and readout equipment for positioning the antenna is in a separate control room. Like the driver of an automobile, the operators of the servo system control and operate the equivalent elements — steering wheel, brakes, clutches, etc. — and in the same sense "drive" the antenna. They are responsible for the safety and efficiency of its operation, and the safety of personnel who might be working on the antenna.

Pointing the Antenna

The antenna, like an ear trumpet, receives most strongly the signals coming from a point directly in front of it. Therefore, it is necessary to keep the antenna pointed in the direction of the space vehicle to receive its signals. To accomplish this, the servo system of the Robledo tracking station normally operates in what is called an automatic tracking mode: Angle tracking is provided by special angle-error receivers and an angle-sensing antenna feed. If the signal comes from a direction slightly off the axis of the dish, the angle-sensing feed provides a signal to the antenna servo system in the proper sense and strength to drive the dish so that its axis points directly at the spacecraft signal source as the spacecraft moves across the sky. All parts of the antenna structure are so precisely balanced and aligned that, heavy as it is, the antenna can be rotated at rates up to 1 degree per second.

Pointing-angle information based on computer-calculated predicted trajectory data may be supplied to the station in advance of the actual launch of the spacecraft, and is then verified by actual trajectory data from early passes over the DSIF sites, particularly first-acquisition data from Johannesburg or Ascension Island. With accurate information on the time and position at which the spacecraft will appear in the antenna field of view, no time is lost in locating the spacecraft.

Aligning the Antenna

The Robledo station has a collimation tower—located about two miles from the antenna—which is used in testing and adjusting antenna alignment and operation. A test antenna, a transmitter-receiver unit, and optical targets are mounted on the collimation tower. The tower simulates spacecraft signals for testing antenna and station operation. Visual checking of antenna boresighting (adjusting the line of sight, similar to aligning gun sights) is done in conjunction with an optical tracking package mounted on the 85-foot antenna, which consists of a television camera, a 35-mm-film boresight camera, and an optical telescope. This equipment may also be used for optical tracking of luminous celestial objects such as the Moon, planets, and stars. Radio stars of known position are also tracked by the antenna to verify pointing accuracy and other performance factors.

Robledo de Chavela

The Deep Space Network

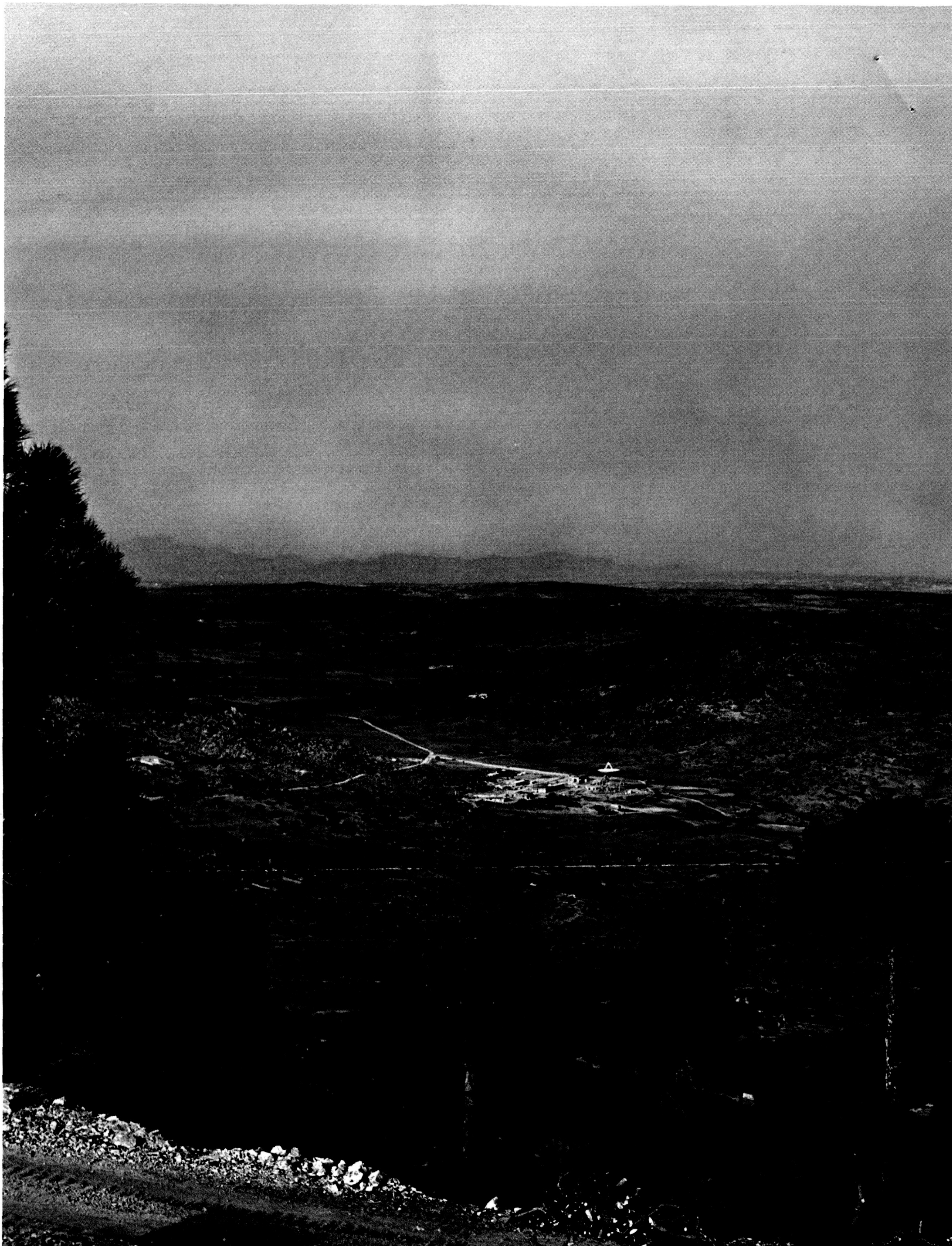
The Deep Space Network (DSN) is one of several world-wide data-acquisition networks established by the National Aeronautics and Space Administration's Office of Tracking and Data Acquisition. The DSN operates under the system management and technical direction of the Jet Propulsion Laboratory. The main elements of the DSN are the Deep Space Instrumentation Facility (DSIF), with space communication and tracking stations based around the world; the Space Flight Operations Facility (SFOF) at JPL in Pasadena, California, U.S.A., which is the command and control center; and the Ground Communication System, which connects all parts of the DSN by telephone, high-speed data lines, and radio-teletype.

Stations of the DSIF are situated approximately 120 degrees apart in longitude so that the spacecraft is always within the field of view of at least one of the ground antennas. The DSIF locations are at Robledo de Chavela near Madrid, Spain; Woomera and Tidbinbilla, Australia; Goldstone, California, U.S.A.; Johannesburg, Republic of South Africa; and Ascension Island, South Atlantic Ocean. Support facilities include a spacecraft monitoring station at Cape Kennedy, Florida, U.S.A.

In addition to the Deep Space Network, NASA operates other spacecraft tracking facilities. These include the Scientific Satellite Network, which tracks Earth-orbiting scientific and communication satellites, and the Manned Space Flight Network, which tracks the manned spacecraft of the *Gemini* and *Apollo* programs. The DSN is designed for two-way communications with unmanned space vehicles with destinations more than 10,000 miles from Earth.

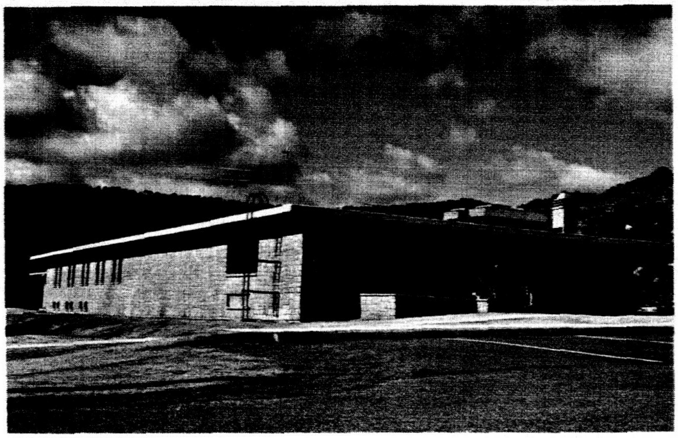
The Deep Space Network participated in the highly successful *Ranger* series of TV-picture-taking missions to the Moon, and in the *Mariner* flyby mission to Mars which sent back the first close-up TV pictures of that planet. In the near future the DSN will communicate with NASA's *Lunar Orbiter*, designed to obtain additional pictures of the Moon's surface, with *Surveyor*, an advanced spacecraft that will land on the Moon, and with *Pioneer*, a solar-orbit probe. In coming years the DSN will take part in the *Voyager* program to explore the near planets, and will support the *Apollo* program in a back-up role.

The impact of space explorations is felt throughout the world, but most profoundly by those nations who actively participate in DSIF operations.



FACING: *The Robledo Space Communications Station is located in a valley near Robledo de Chavela, far from man-made noise that would interfere with the sensitive antennas.*

RIGHT: *Robledo Station operations and engineering building.*



Robledo Space Communications Station

The Governments of Spain and the United States have entered into a cooperative agreement to establish and operate stations of the Deep Space Instrumentation Facility (DSIF) in Spain. The Spanish Instituto Nacional de Técnica Aeroespacial (INTA) is working with employees and contractors of the Jet Propulsion Laboratory in the construction, operation, and maintenance of the DSIF stations near Robledo.

Each DSIF station is equipped with a polar-mounted 85-foot-diameter paraboloidal antenna and associated equipment for communication with spacecraft at lunar distances and out into space millions of miles from Earth. The tracking stations must be located away from man-made electrical and commercial radio interference, and it is desirable that they be located in natural bowl-shaped terrain to provide further shielding from interference.

Such a site was found in the rocky valleys near Robledo de Chavela, about 40 miles west of the Spanish capital city of Madrid. The station is in an area that could be expanded to accommodate other deep space tracking stations without mutual interference.

Investigation of a number of possible sites in Spain began in January 1963. Detailed site-selection studies by engineers from INTA and JPL continued through the spring of 1963. After the most desirable site was finally selected, arrangements were made for the use of the land, and actual construction began in August 1964. Grading and underground foundations were completed that year, and then work began on the huge antenna and the support buildings. By May 1965, the new station was ready for system checkout, which was successfully completed in time for the new station to participate in tracking the *Mariner IV* spacecraft. Thus in its first weeks of operation, the Robledo station shared in one of man's historic achievements in the exploration of our solar system – obtaining close-up television pictures and scientific data from the planet Mars.

Robledo DSIF Station

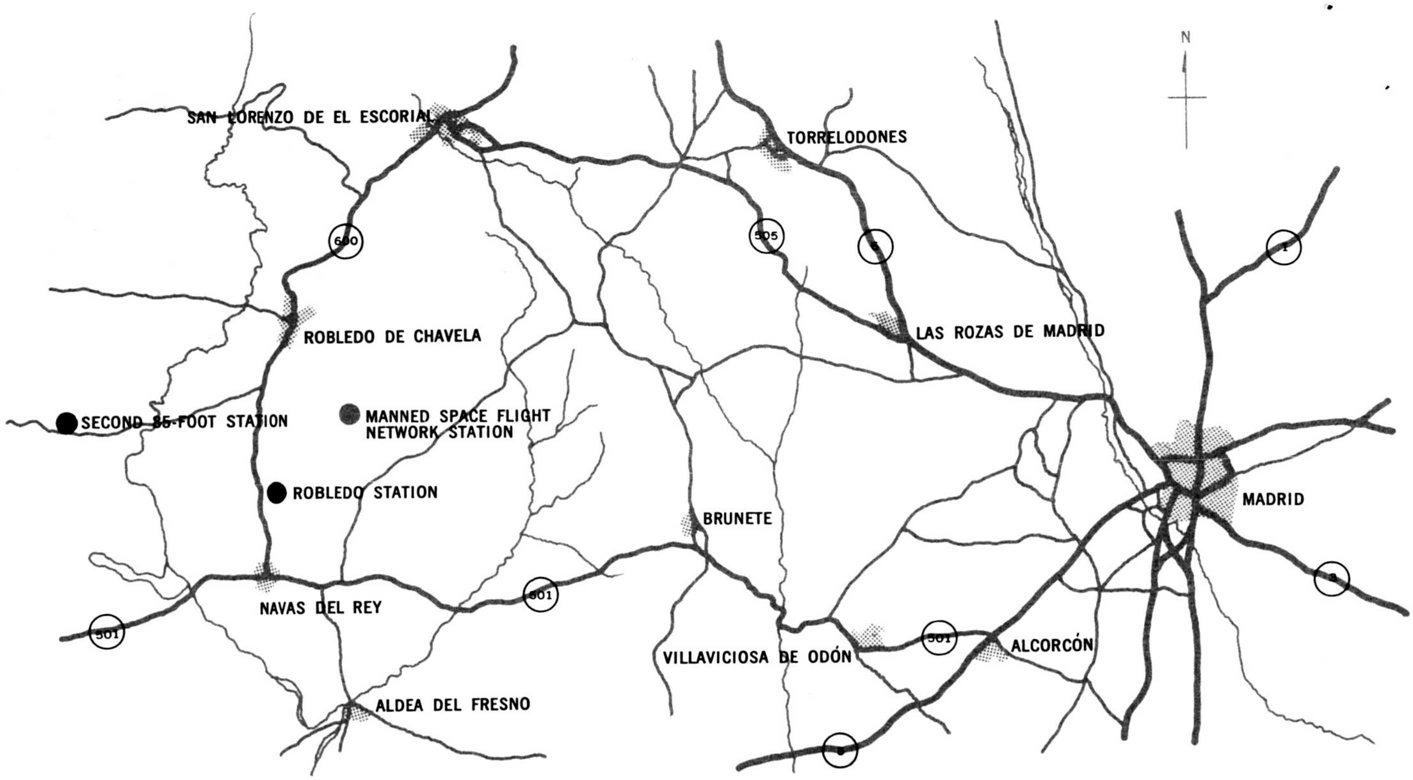
Robledo is a self-sufficient station, with its own access roads, and its own maintenance and repair facilities. It has its own power-generating equipment and telephone system.

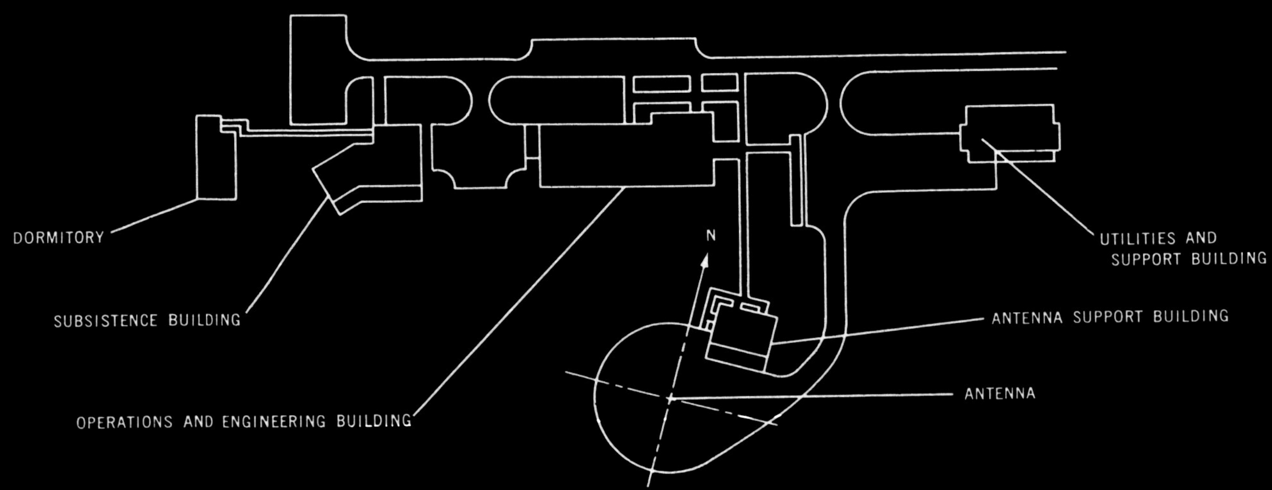
The station may be operated up to 24 hours a day, seven days a week, when required. At present, a private industrial firm supplies technical personnel who assist in the operation and maintenance of the station's electronic equipment under the direction of the JPL station manager. A staff of engineers from INTA and JPL act as technical consultants to the station manager.

Many of the key operating personnel performed acceptance tests on the electronic equipment when it was checked out at Goldstone, California, before shipment to Robledo.

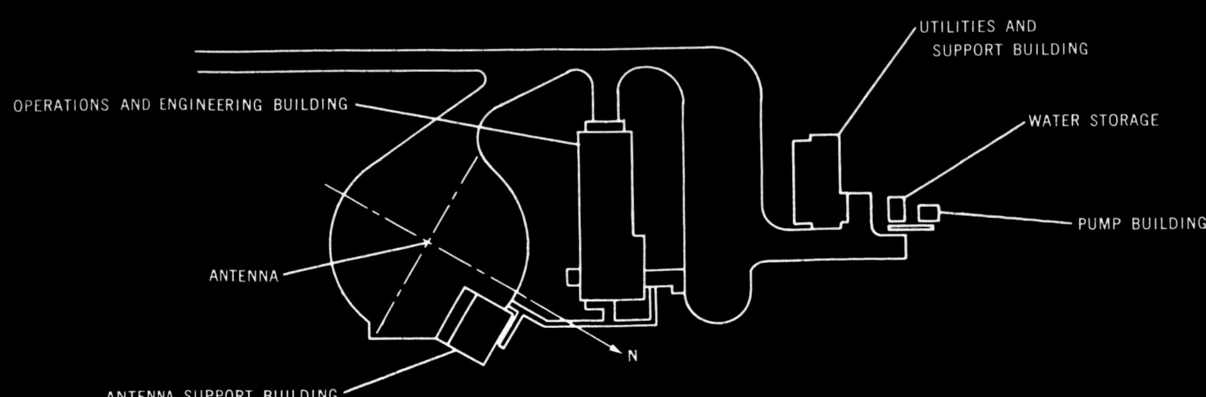
The major facilities at the station are:

1. An operations and engineering building that houses the majority of the tracking, telemetry, and communications equipment as well as laboratories and offices.
2. A utilities and support building that houses the power-generating and switching equipment and workshop facilities.





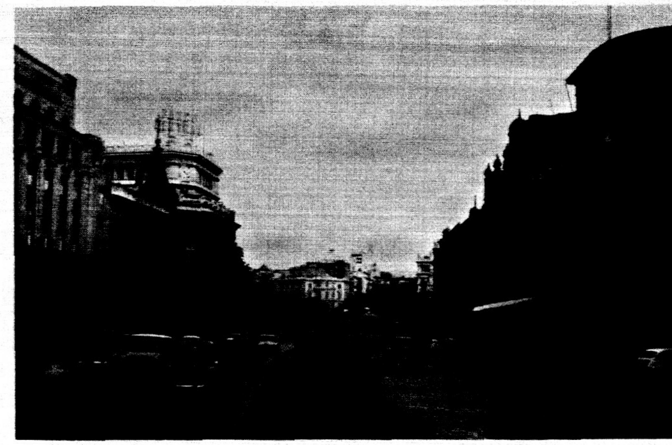
ROBLEDO STATION



SECOND 85-FOOT STATION

FACING, TOP: *Map shows location of the Robledo DSIF stations, about 40 miles west of the Spanish capital city of Madrid.* BOTTOM: *Station ground plans.*

RIGHT: *Calle de Alcalá, Madrid*



3. The 85-foot-diameter antenna and an antenna support building that contains the hydromechanical equipment for the antenna plus the power amplifier portion of the radio transmitter.
4. A subsistence building that provides dining facilities for the staff of the station.
5. A dormitory building that provides limited sleeping accommodations for use when the station must be in full-time operation.
6. A collimation tower and a small building to house the collimation equipment located about two miles from the main antenna. A source of radio energy that simulates spacecraft signals is mounted in the collimation tower. This equipment is used to calibrate and check the performance of the main antenna and associated electronic systems, and to conduct antenna alignment checks.

In DSIF operations, Robledo performs the functions of *tracking*—locating the spacecraft, measuring its distance, velocity, and position, and following its course; *data acquisition*—gathering information from the spacecraft; and *command*—sending instructions from the ground that guide the spacecraft in its flight to the target, and tell the spacecraft when to perform required operations and when to turn on the instruments for performing the scientific experiments of the mission. The station operates in the radio-frequency channel allocated to the DSIF. These frequencies are in the S-band, and range from 2110 to 2120 Mc (million cycles per second) for transmission of commands from Earth to the spacecraft, and from 2290 to 2300 Mc for receiving signals from the spacecraft.

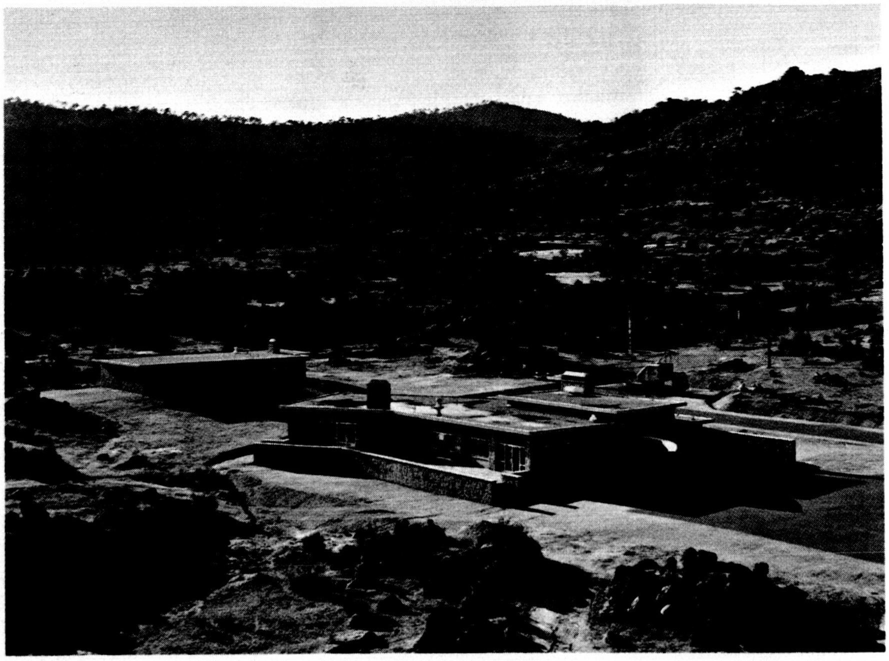
Each space flight project requires equipment and accommodations unique to that project, dependent upon the type of command system to be used and the type of telemetry system the spacecraft will carry. Sometimes this may just mean a rearrangement of station equipment. When mission-dependent equipment is required by a project, it is supplied to the station by the responsible project organization, and arrangements are made in advance for it to be integrated with the normal complement of station equipment.

Madrid Area

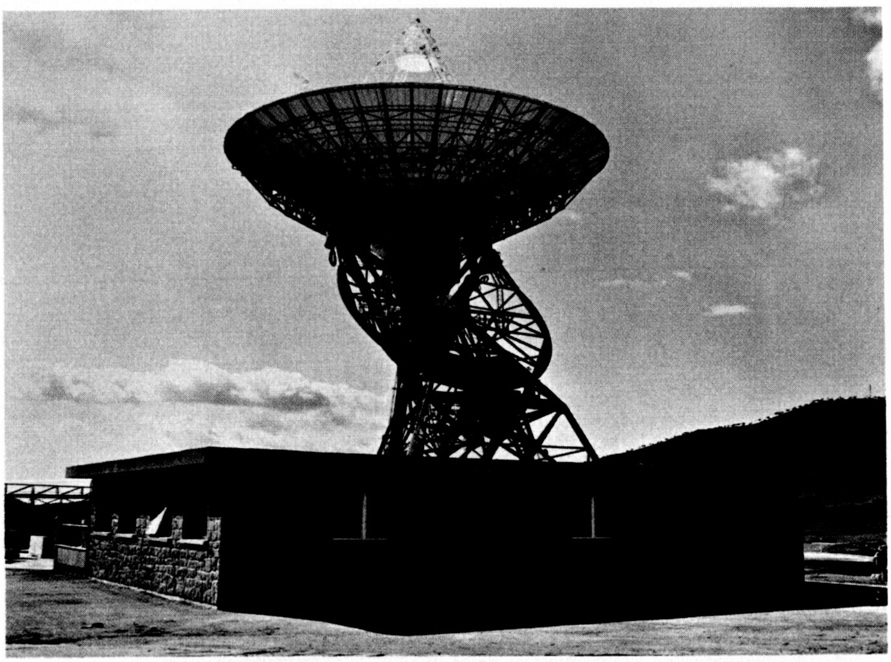
The DSIF station is within easy commuting distance of Madrid, the capital and largest city in Spain, which can be reached by automobile over paved roads and by train from Robledo de Chavela. Besides being a nearby source of communication and transportation facilities, Madrid provides housing for the families of many of the station personnel.

Madrid was but a tiny village at the time Columbus embarked on the historic exploration for King Ferdinand and Queen Isabella of Spain, which was the counterpart of today's space exploration. It was not until Phillip II chose this plateau in the geographical center of the country for the royal residence that Madrid began to develop into the modern city found there today. Construction is visible everywhere and modern skyscrapers are now mixed with more historic structures along the streets and squares of the city. Madrid offers as much in the way of cultural, artistic, and entertainment facilities as any of the capitals of Europe—of first importance, perhaps, is the world-famous Prado Museum.

Robledo de Chavela is located about 40 miles west of Madrid in the El Escorial region. The region takes its name from the huge El Escorial palace built by King Phillip II to honor St. Lawrence. This truly massive structure, built on the side of the Guadarrama hills, consists of twelve acres of buildings connected by over one hundred miles of corridors. The main structure now serves primarily as a monastery and as a tomb for the kings of Spain, from Charles I on.

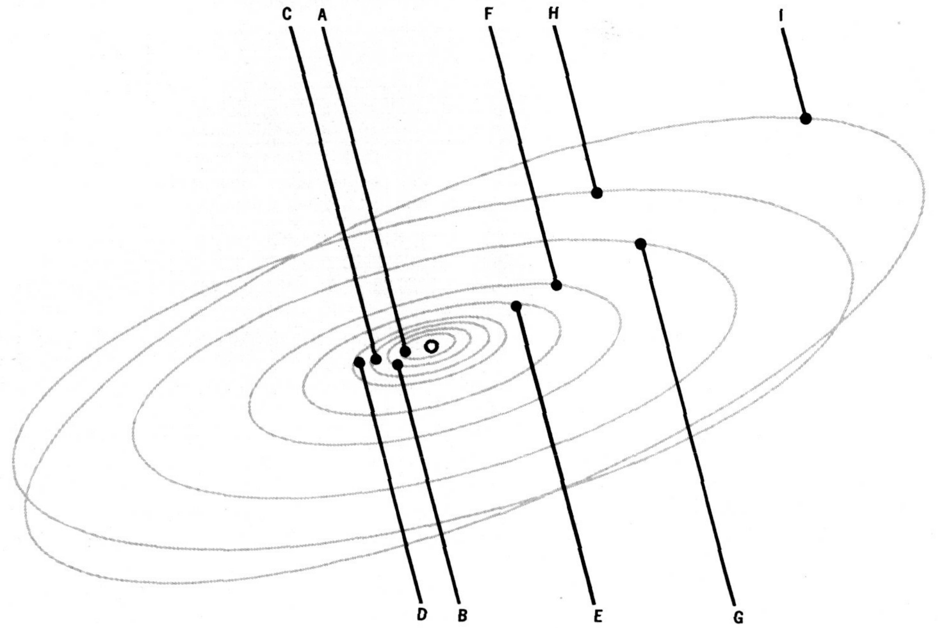


Subsistence building in foreground; dormitory in background.



Antenna support building.

Utilities and support building.



A. MERCURY	36,000,000
B. VENUS	67,000,000
C. EARTH	93,000,000
D. MARS	142,000,000
E. JUPITER	484,000,000
F. SATURN	886,000,000
G. URANUS	1,783,000,000
H. NEPTUNE	2,793,000,000
I. PLUTO	3,666,000,000

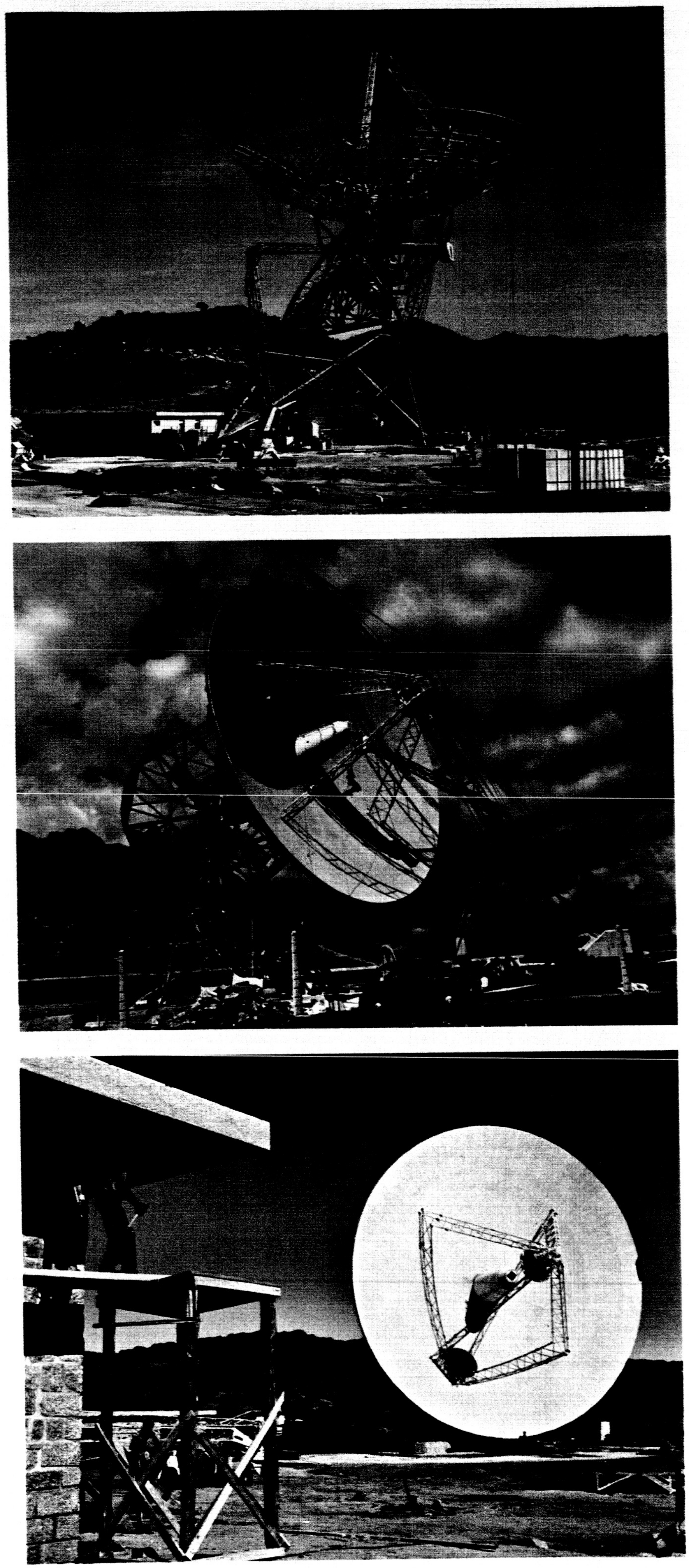
COMMUNICATION WITHIN OUR SOLAR SYSTEM INVOLVES TREMENDOUS DISTANCES. SHOWN ABOVE ARE DISTANCES OF THE PLANETS FROM THE SUN IN MILES.

frequency. Two-way doppler developed for the DSIF has increased this accuracy to better than one inch per second. In two-way doppler, a signal is transmitted from the ground to a turn-around transponder (receiver-transmitter) on the spacecraft, where it is converted to a new frequency in an exact ratio with the ground frequency, and then retransmitted to the ground. Since the frequency of the signal sent from the ground can be determined with great precision, the resulting doppler information and velocity calculations are very accurate. By two way doppler calculations alone the position of a spacecraft at a distance of several million miles can be determined within 20 to 50 miles. A JPL-developed electronic ranging system uses an automatic coded signal in conjunction with doppler information to provide range measurements with an accuracy better than 45 feet at lunar and planetary ranges.

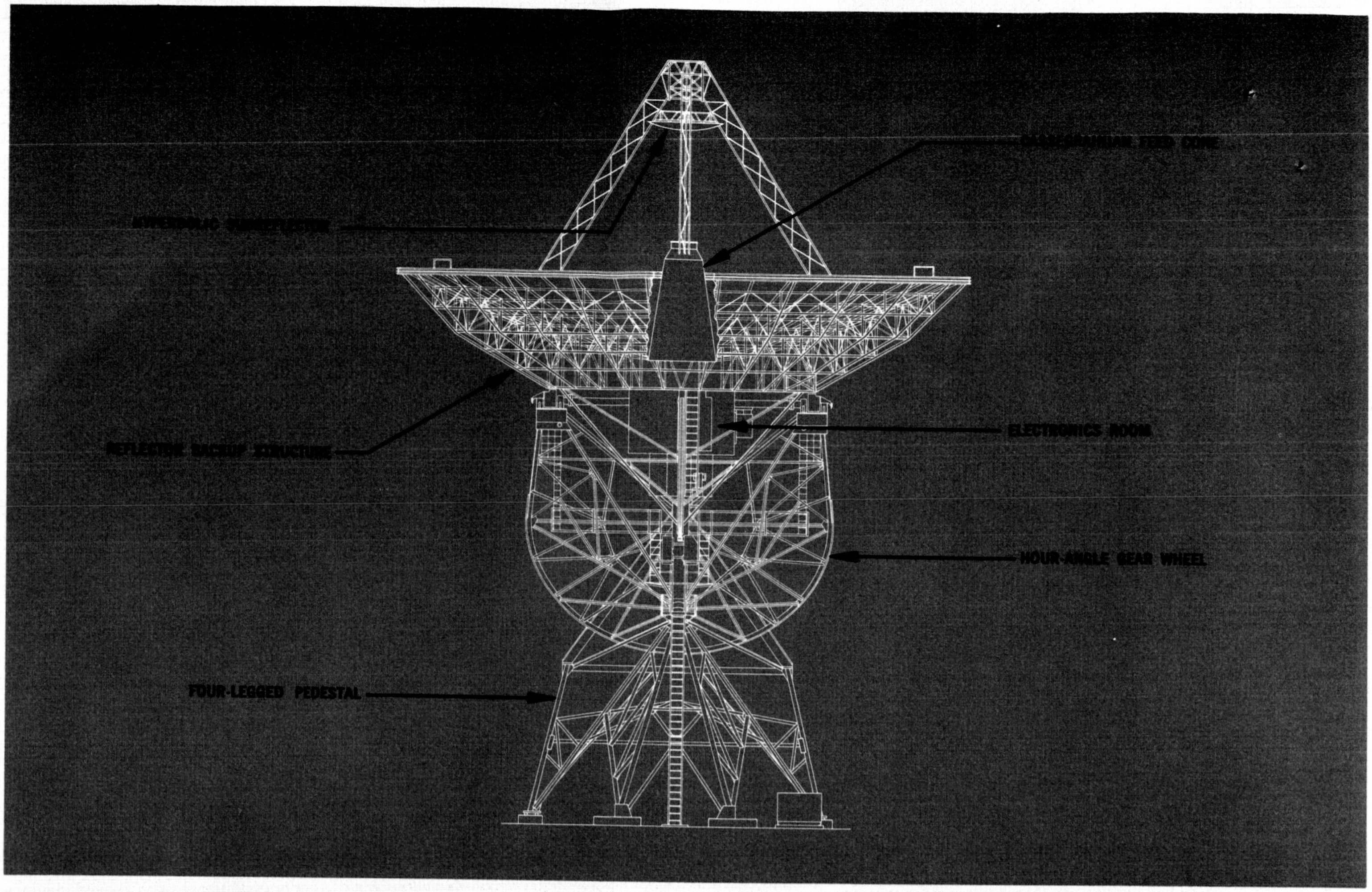
Because of the doppler shift and other effects, the frequency of the signal received on the ground from the spacecraft varies widely, which means that receiver tuning must be continually changed. Both spacecraft and DSIF ground receivers use a phase-lock method of signal detection, which maintains an automatic frequency control and keeps the receiver locked in tune with the received frequency.

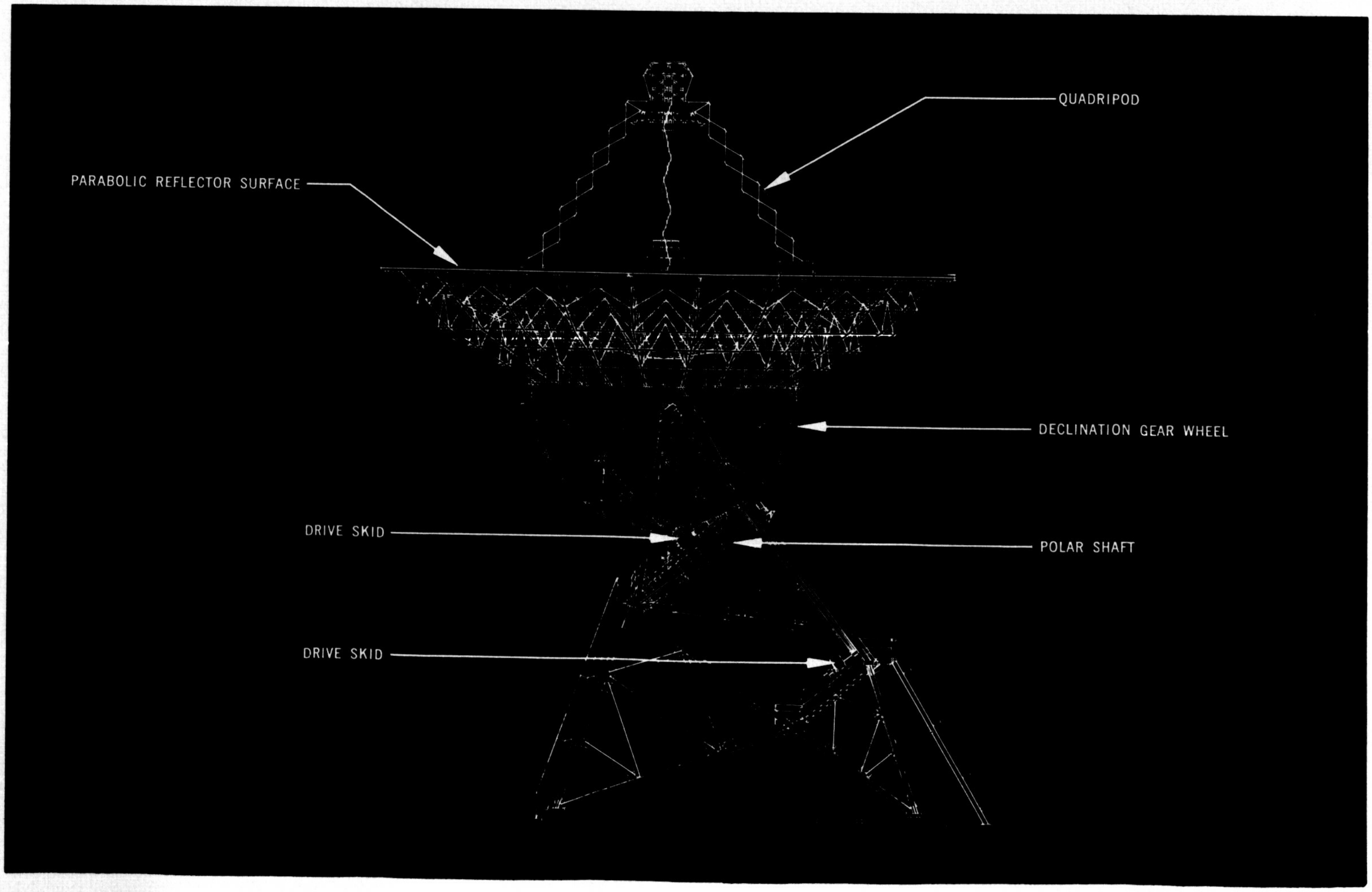
Receiver performance is measured by the ability to pick up the weak signal from the spacecraft transmitter and separate it from surrounding noises (static) originating not only in the Earth's atmosphere, but from lunar, solar, and galactic sources. DSIF receivers have a very low threshold—the point at which the receiver can no longer detect the signal, just as in human hearing, the lower limit at which the ear no longer responds to a sound is the threshold of hearing. And just as internal body sounds (such as that of blood coursing through the head) interfere with the lowest external sound discernible to the human ear, radio receiver sensitivity is affected by internal electronic noise in the system itself. To help overcome this problem, advanced methods of ultra-low-noise signal amplification have been developed. DSIF S-band receiving systems use a traveling-wave maser amplifier. The maser is basically a synthetic ruby crystal, which is immersed in liquid helium to keep it at a very low temperature, and operates with a "pumped-in" source of microwave energy to augment the strength of the incoming signal without generating much internal system noise.

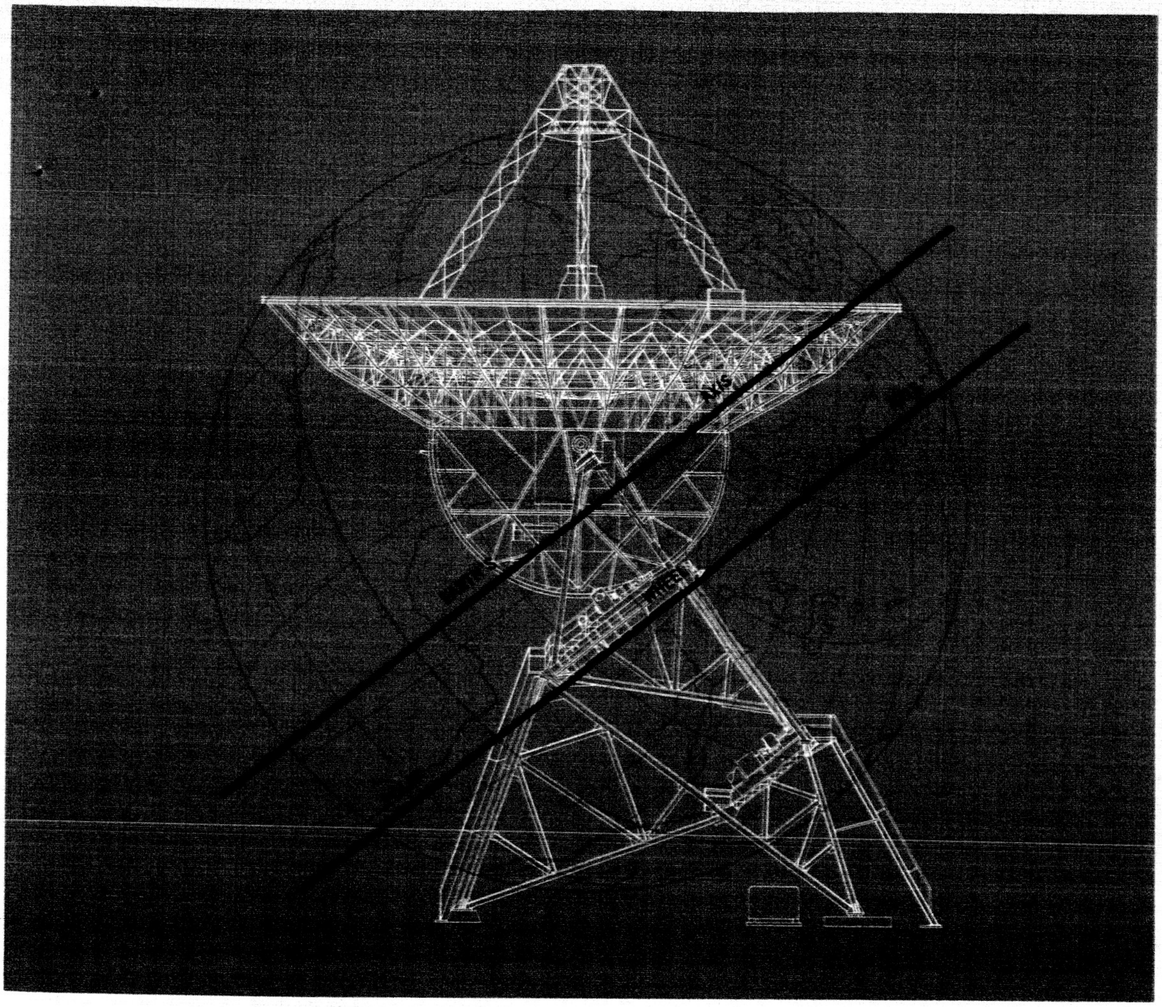
The basic components of the spacecraft communications systems in the DSIF are essentially the same, although auxiliary equipment may vary depending upon the special requirements for scheduled missions. The following pages describe the system installed at Robledo. The complete system comprises thousands of different elements which must work perfectly under precision requirements.

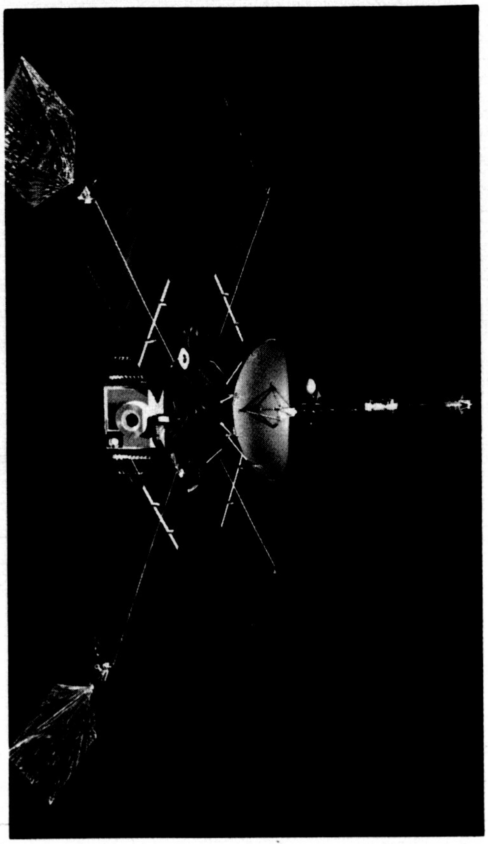


Construction of the Robledo Station was started in August 1964. Photographs show stages of erection of an 85-foot-diameter antenna.

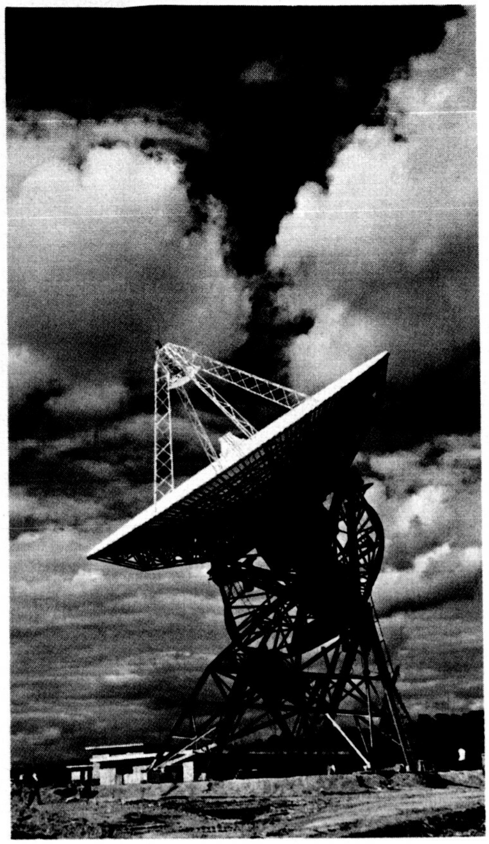

HYPERBOLIC SUBREFLECTOR
CASSEGRAINIAN FEED CONE
REFLECTOR BACKUP STRUCTURE
ELECTRONICS ROOM
HOUR-ANGLE GEAR WHEEL
FOUR-LEGGED PEDESTAL


QUADRIPOD
PARABOLIC REFLECTOR SURFACE
DECLINATION GEAR WHEEL
DRIVE SKID
POLAR SHAFT
DRIVE SKID



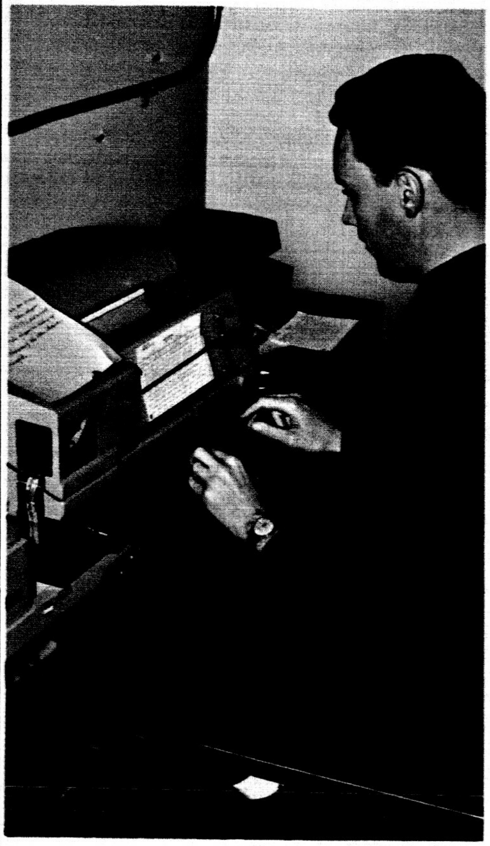


1. Engineering measurements and scientific data generated by instruments aboard the spacecraft are radioed to Earth by the spacecraft transmitter.

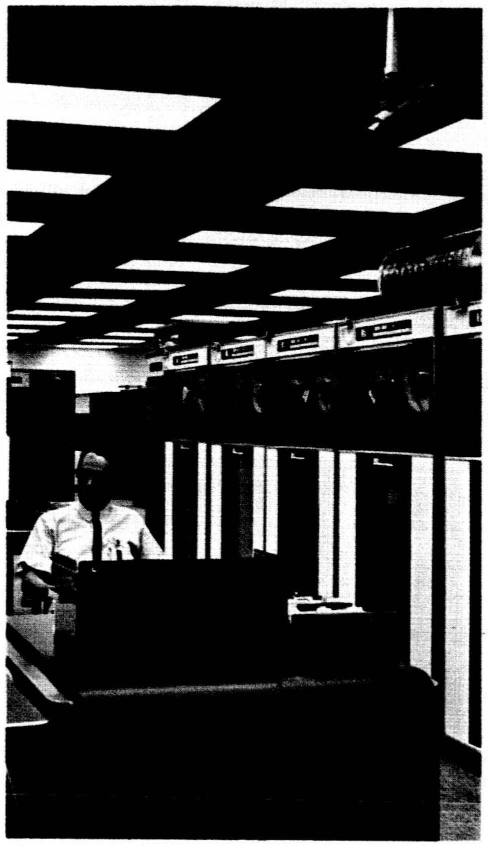


2. The radio signal, greatly reduced in strength because of the distance it travels, is captured by the Earth antenna.

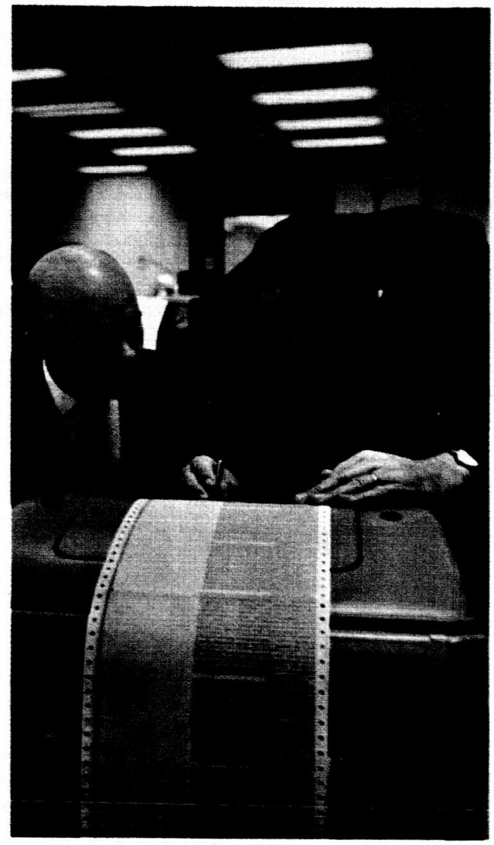
3. The signal is amplified and processed throug the receiving system, and information from th signal is translated and recorded on magnet and punched paper tape.



4. Data gathered at the Robledo Station are transmitted by teletype and high-speed digital data lines to the SFOF at JPL in Pasadena, California.



5. At the SFOF control center, information is processed by computers into usable form for analysis by scientists and engineers.



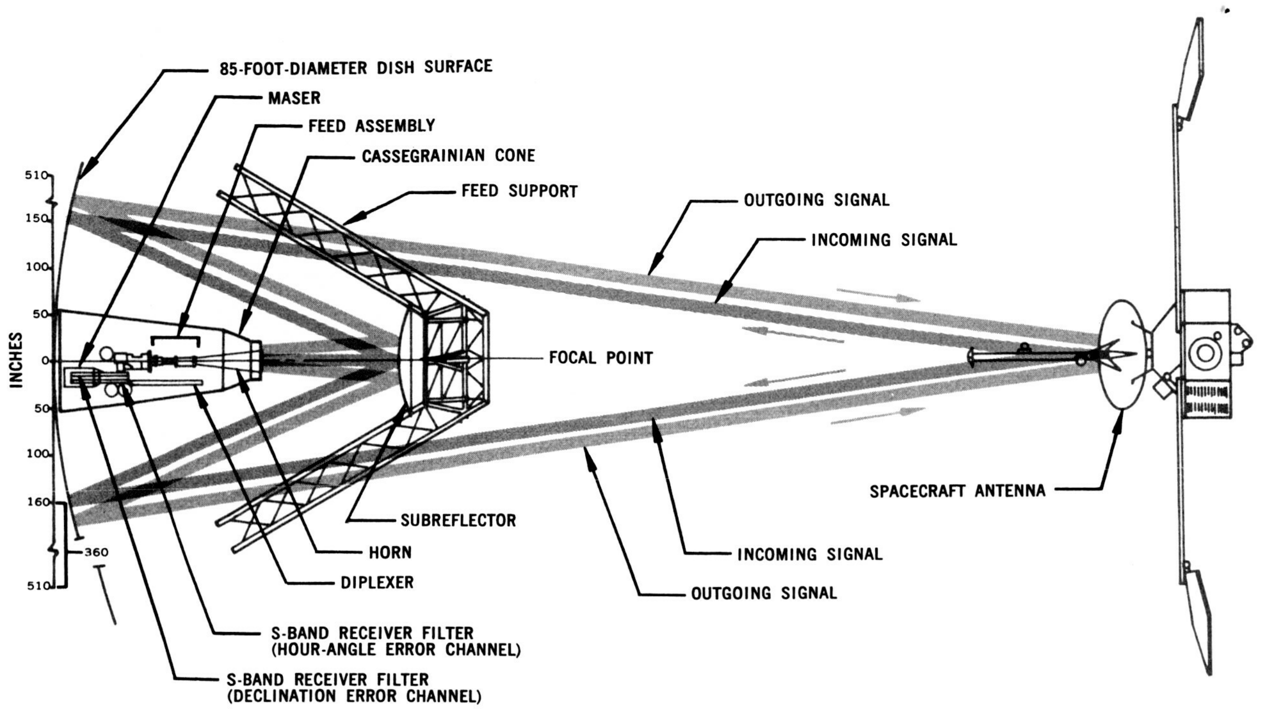
6. Processed data present video, tracking, engineering, and scientific telemetry in the form of time-labelled numerical printouts or graphs. All processed data are stored on magnetic tape.

Tracing a Signal Received From the Spacecraft

The reflecting surface, or dish, of the 85-foot antenna reflects the radio energy from the spacecraft transmitter into the sensitive DSIF receivers. The antenna, with an area of almost 6000 square feet, can collect signals so faint that the radio-frequency energy is calculated to be about equivalent to that radiated by a 1-watt light bulb at a distance of approximately 75 to 80 million miles.

In general, shorter radio-frequency connections between the antenna signal feed system and the receiver mean greater antenna efficiency. DSIF antennas for S-band operation have a Cassegrainian cone feed system mounted at the center, or focal point, of the reflector, which allows very short connections. This system is similar in design to that of a Cassegrainian telescope used in optical astronomy. Radio waves reflected by the main dish are focused onto a subreflector mounted on a truss-type support that extends about 36 feet from the center of the dish. The subreflector then focuses the waves into a feed horn in the Cassegrainian cone. The signal is fed directly from the feed horn to the low-noise maser amplifier, so that maximum amplification of the weak signal occurs before it is contaminated by the electronic noise of the rest of the receiver system.

The S-band phase-lock receiver has four separate receiving channels: two reference channels (called sum channels) for doppler information, spacecraft telemetry, and TV signals; and two channels that carry angle-tracking signals for antenna pointing. The information from each of the sum channels is dispersed by distribution amplifiers in the receiver system to proper destinations in the telemetry instrumentation and data-handling systems in the control room.



THE CASSEGRAINIAN FEED SYSTEM IS THE FOCAL POINT FOR RECEIVING AND SENDING SIGNALS. THE DIAGRAM SHOWS HOW OUTGOING AND INCOMING RADIO WAVES TRAVEL BETWEEN THE GROUND ANTENNA AND SPACECRAFT ANTENNA.

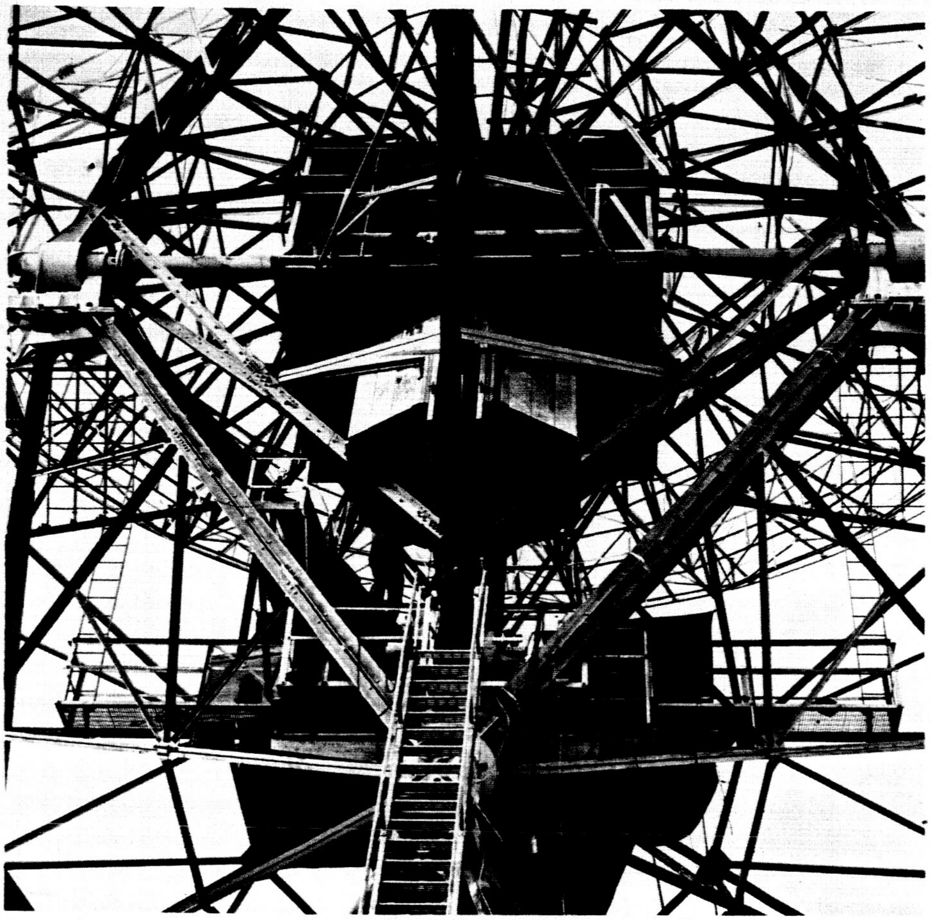
Sending a Command to the Spacecraft

Changes to the trajectory of a deep space probe are controlled by transmitting command signals that initiate roll, pitch, and yaw maneuvers, as well as propulsion, ignition, and timing sequences. Commands to be sent to a spacecraft are determined by computations made from tracking data. Signals are also sent to the spacecraft to change data rates, change the type of telemetry information being transmitted, turn the transmitter on or off or change its power, reorient the spacecraft or its antennas, or even to switch antennas, receivers, and transmitters.

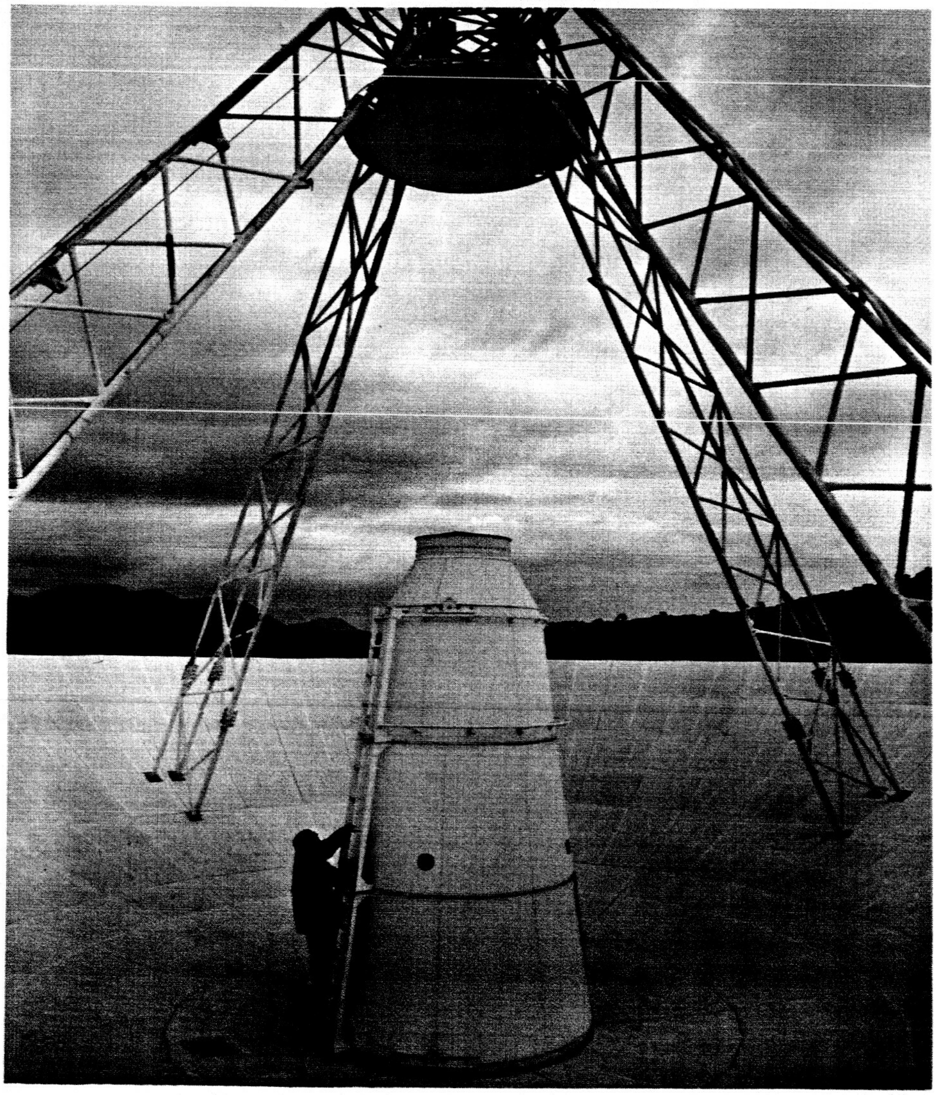
Sending a command to the spacecraft is somewhat the reverse process of receiving a signal. The transmitting station is equipped with a 10-kilowatt transmitter. The exciter and controls of the transmitter are in the control room; the radio-frequency power amplifier and associated equipment are mounted in the antenna support building and up on the antenna. The power level of the signal produced by the exciter is very low—only a few watts. This is amplified in the power amplifier so that the signal radiated from the antenna is very strong—approximately 10,000 watts. The transmitter is normally used with a diplexer, which is a device designed to allow simultaneous operation of both transmitter and receiver at different frequencies on a single antenna and feed system.

The commands to be sent to the spacecraft originate in the JPL SFOF control center in Pasadena, California. Command information is sent over the teletype link from Pasadena to the station at Robledo.

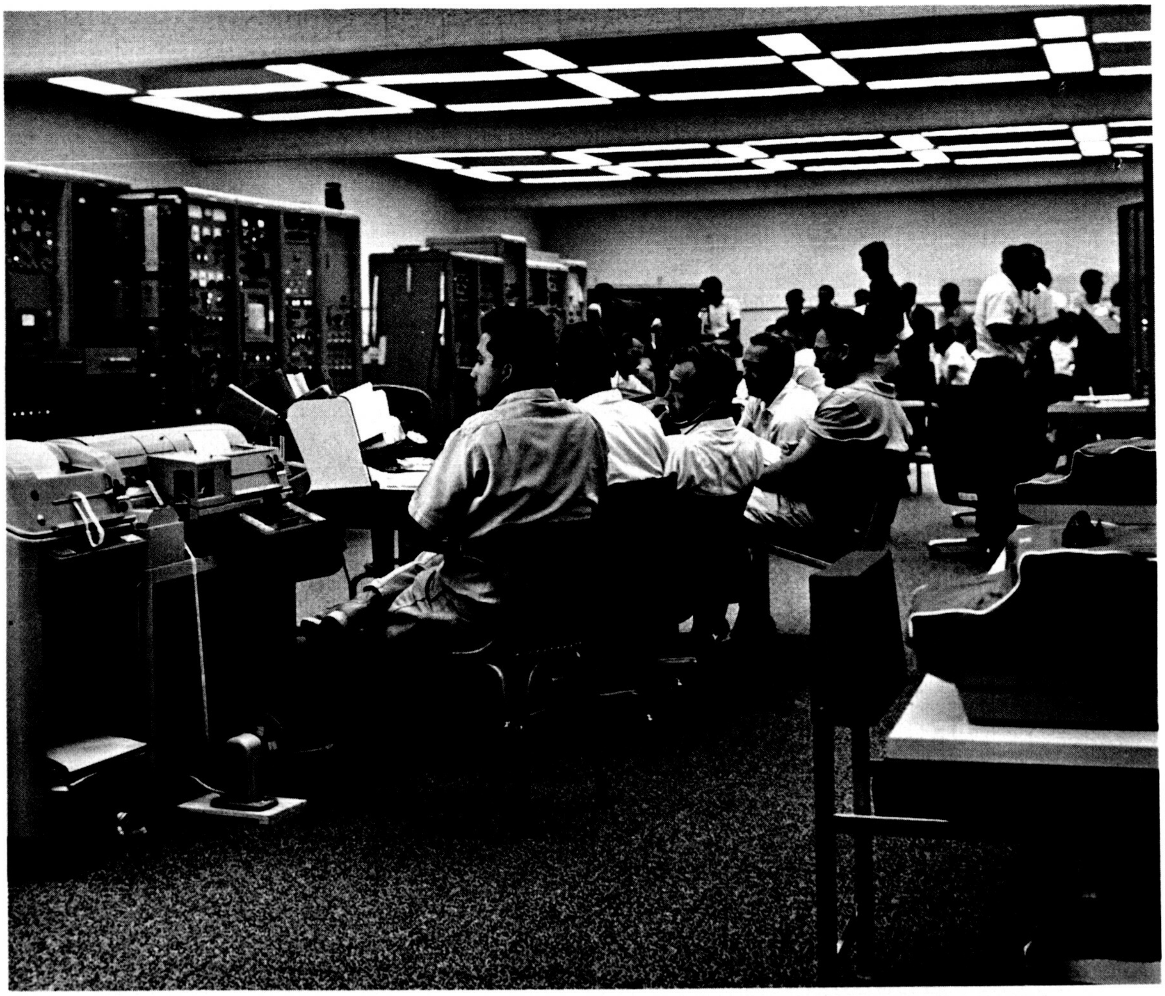
An incorrect command could result in possible damage to the spacecraft. Therefore, extreme precautions are taken to ensure accuracy. Command information from the SFOF is usually sent three separate times over the teletype links to the command station, and is also verified by voice over the telephone. Ground command and control equipment at the station includes read-write-verify equipment that carefully checks a command before it is sent and as it is being sent to the spacecraft. This special equipment reads and verifies the teletype message, transforms the command into a signal for radio transmission, and monitors the transmitted radio-frequency signal bit-by-bit. If any bit proves incorrect, transmission is automatically stopped to make correction. Very often, especially if the command is to be stored in the spacecraft memory equipment for later execution, the command as received by the spacecraft is telemetered back to the ground and checked again with the transmitted command. A special-purpose computer is used just to execute these check routines.

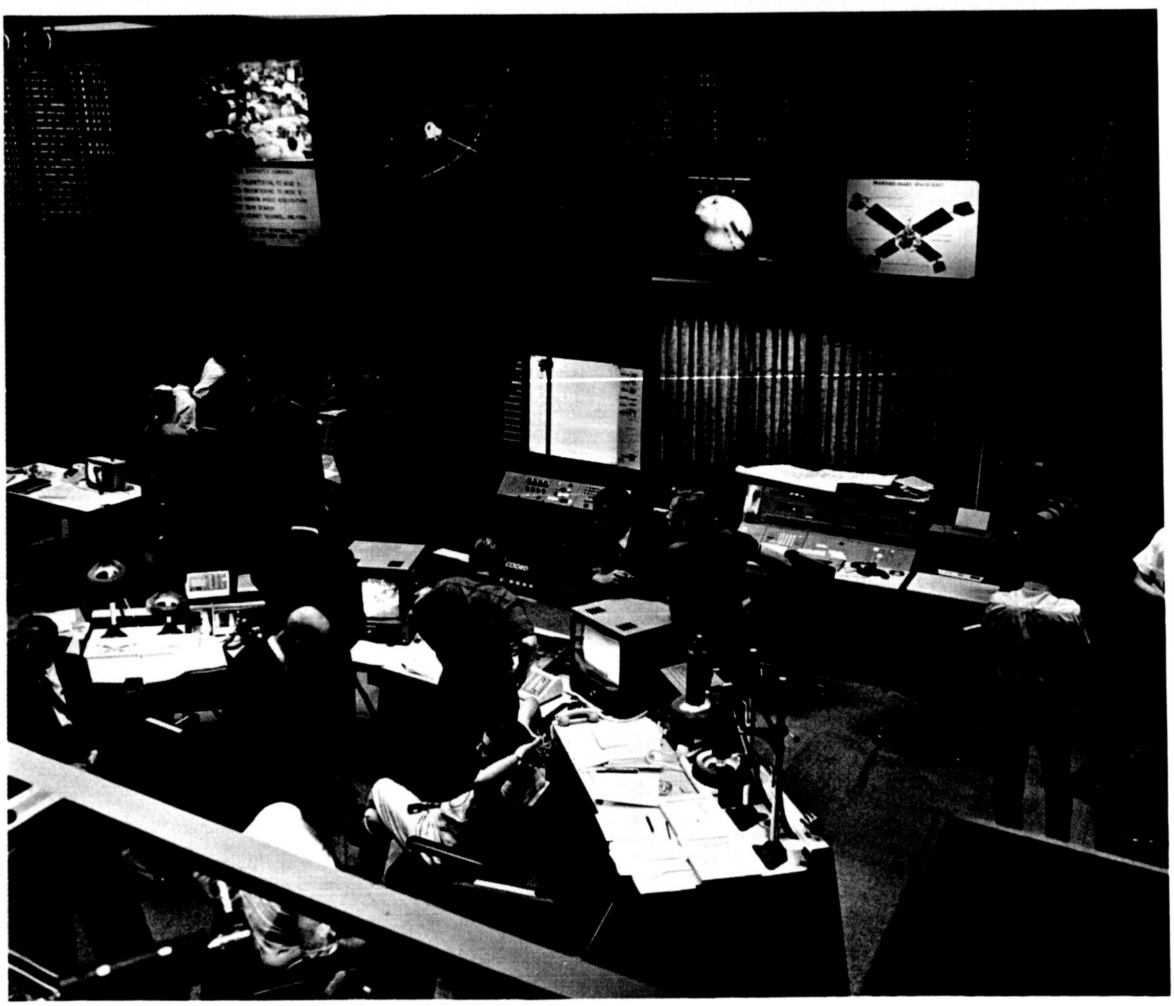


The 10-kilowatt transmitter, which gives an effective radiating power of 2.5 billion watts for sending signals into space, is located in the electronics room on the antenna (shown here during construction).



Cassegrainian feed cone is mounted in the center of the antenna reflector.





FACING, TOP: *Center of operations at the Robledo Station is the control room. Consoles lining the walls contain the controls for the receiver, transmitter exciter, and servo system, and the ground instrumentation and data-handling equipment.*

FACING, BOTTOM: *At the SFOF center in Pasadena, data gathered by the DSIF are used by engineers in space flight control operations and analysis of mission results.*

Translating the Information From the Spacecraft

Signals processed by the receiver are sent to ground instrumentation and data-handling equipment in the control room. This includes paper-tape and magnetic-tape recorders, and ultraviolet oscillographs.

Tracking-data-handling equipment records angle measurements of antenna position, doppler frequency measurements, range measurements, and time. These data are recorded on paper tape for immediate teletype transmission to the SFOF in Pasadena for use in spacecraft orbit determination, calculation of maneuver parameters, command decisions, and prediction of arrival time at the target.

Telemetry signals from the spacecraft that come in on the receiver sum channel are either time- or frequency-multiplexed; that is, the signals from the various measuring instruments on the spacecraft are carried on one composite radio-frequency signal, either sequentially (time-multiplexed) or simultaneously on several subcarrier frequencies (frequency-multiplexed). This composite signal is "unscrambled" by demodulators in the ground telemetry system. Analog or digital (or both) methods of signal modulation are used for transmission of data from the spacecraft to Earth.

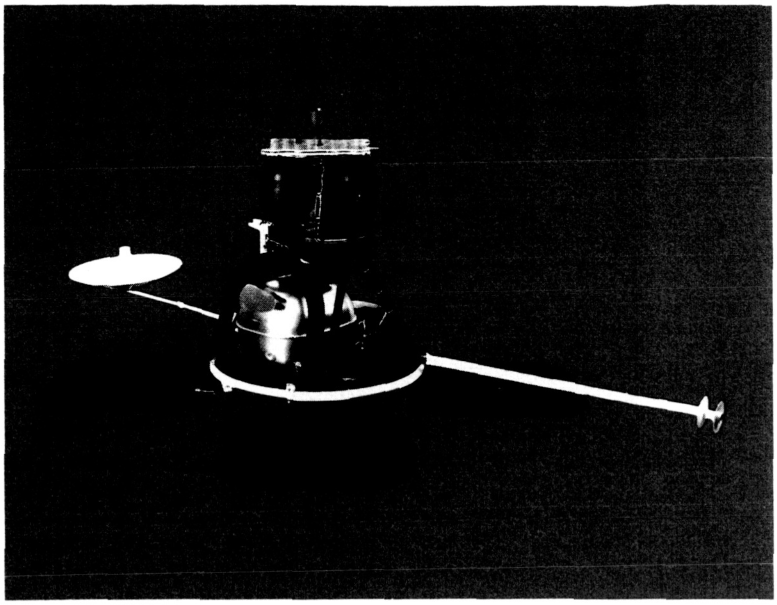
Analog modulation transmits engineering measurements in continuously varying electrical signals that represent measurements of voltages, temperatures, pressures, radiation intensity, etc. With coded digital modulation techniques, it is possible to increase the efficiency of data transmission from the spacecraft. Digital transmission also simplifies data handling at the ground station because digital signals can be formatted for direct inputs to computers and for teletype transmission.

The detected, unscrambled signals are recorded on magnetic tape so that complete permanent recordings of all telemetry data from the spacecraft will be available for later data processing either at the SFOF or by the NASA Center responsible for the project. Certain selected spacecraft telemetry signals are displayed at the station as they are received for the use of operating personnel in maintaining contact with the spacecraft.

In addition to processing and recording spacecraft telemetered data, the station also processes and records data generated by the ground equipment, such as received signal strength, transmitted power, and condition of all station equipment. This information is processed by the digital instrumentation system, which uses general-purpose digital computers that accept and process both analog and digital signals.

All taped information sent to JPL is labeled and identified by date, time received, station, and spacecraft number. Because time reference is a critical factor in tracking determinations, and in other DSIF functions that depend upon the timing of electronic phenomena, the time of receipt of telemetry data is recorded to an accuracy of at least one hundredth of a second. All data received during a mission are recorded on magnetic tape for a permanent record and for the use of scientists and engineers in evaluating the results of a mission. Literally hundreds and hundreds of miles of magnetic tape are used in some missions, and final evaluation takes months, and sometimes years, of study.

DSIF acquisition procedures, which include antenna pointing, receiver tuning, transmitter tuning, ranging lock, and telemetry decommutation, are so precisely timed and coordinated that it is possible to start recording data from 1 to 10 minutes after radio contact with the spacecraft is established, and to start transmitting data to the SFOF within 4 to 16 minutes.



LUNAR ORBITER: *Mission—lunar surface photography and gravity field measurements to help select landing sites for Surveyor and Apollo. Mock-up shown.*

DSN Mission Support

In readiness for increasingly expanding activities in space, the Deep Space Network has the capability of controlling operations of as many as four spacecraft in flight at the same time, and advanced communication techniques that make the prospect of probes to planets as far out as Jupiter within the realm of possibility.

The DSN supports the following space exploration projects for which JPL is responsible:

Surveyor. A soft-landing on the Moon of instrumented craft capable of performing operations to contribute new scientific knowledge about the lunar surface and to make final tests in support of the *Apollo* program.

Voyager. An advanced mission that will send unmanned spacecraft to conduct scientific exploration of the planets, beginning with Mars in 1971.

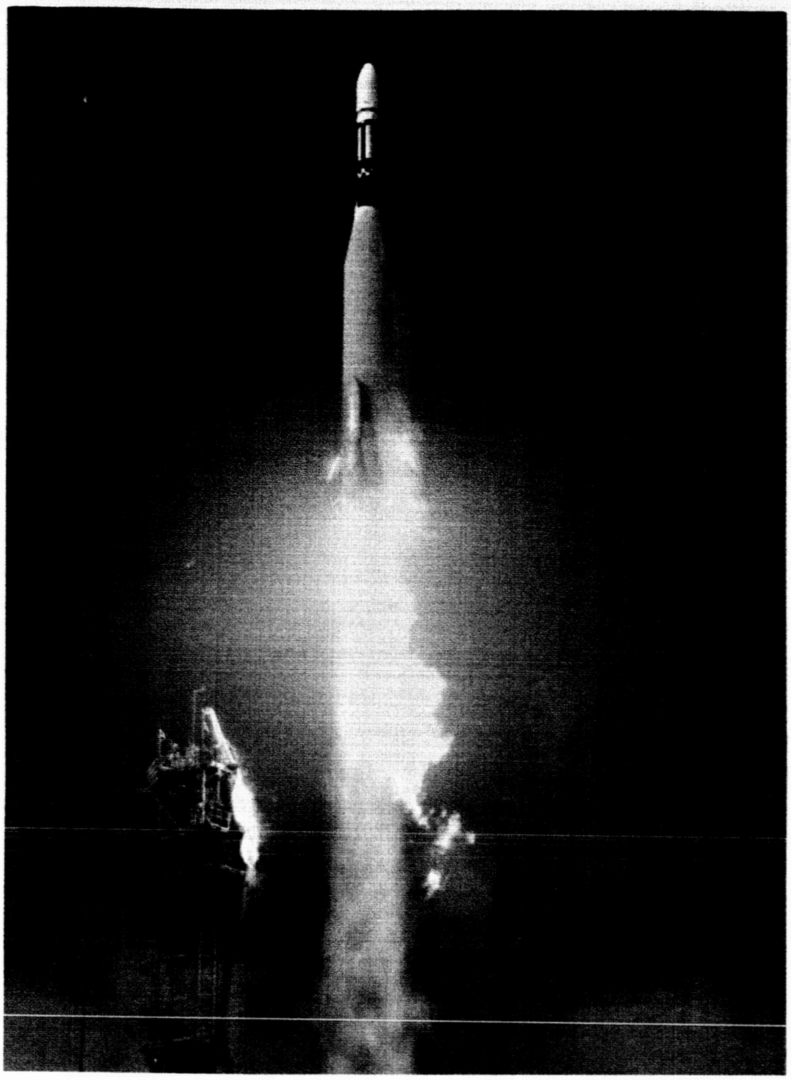
The DSN also supports the following missions for which the NASA agency named with each is responsible:

Lunar Orbiter (Langley Research Center). A photographic mission to take pictures of the lunar surface from a satellite spacecraft.

Pioneer (Ames Research Center). A series of probes designed to penetrate deep into our solar system to learn more about the nature of solar flares and other deep space phenomena.

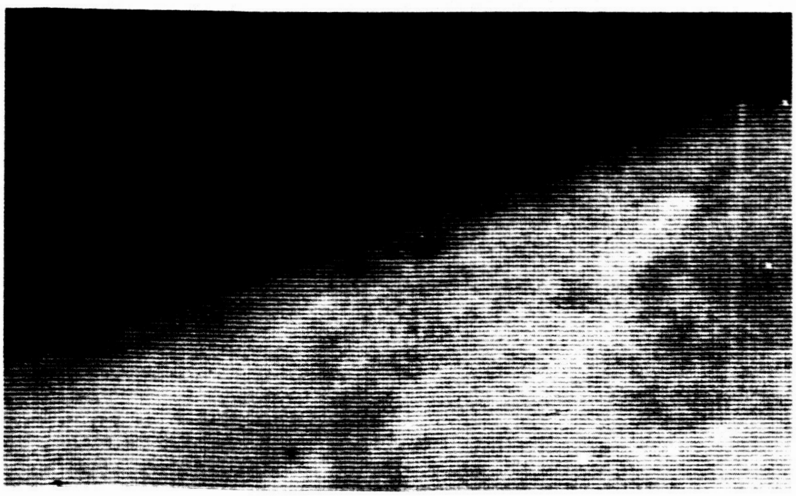
Apollo (Manned Spacecraft Center). The manned spacecraft mission that will put men on the Moon.

As new programs are conceived to extend man's knowledge outward to the edges of the solar system, the Deep Space Network will be prepared to continue as the radio link with these 20th century explorers.



Mariner IV, boosted by an Atlas-Agena rocket, is launched from Cape Kennedy on its 7½-month journey to investigate the planet Mars at close range.

The Robledo Station holds the distinction of receiving and recording the first TV picture signals from Mariner IV.



The world's first close-up picture of Mars, taken by Mariner IV at encounter, July 14, 1965, shows the limb, or outer edge, of the planet.